Understanding Near-Surface and In-Cloud Turbulent Fluxes in the Coastal Stratocumulus-Topped Boundary Layers

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LONG-TERM GOAL

The long-term goal of this project is to understand the spatial and temporal variation of the surface fluxes in relation to the variability of the sea state and the stratocumulus-topped boundary layers and to improve the physical parameterizations of surface flux and boundary layer processes in regional and climate models.

OBJECTIVES

The objective of this project is to understand the spatial and temporal variability of the turbulent fluxes in relation to the sea state and the stratocumulus-topped marine atmospheric boundary layers (MABL) properties. Our work in FY06 focused on the investigation of the causes of difference in turbulence fluxes in along and cross wind sampling with aircraft and bulk estimates, the characterization of flux profiles, and the effect of synoptic scale parameters on boundary layer structure in the area of Monterey Bay. The analysis of aircraft data was supplemented by data from other measurement platforms during the Autonomous Oceanographic Sampling Network (AOSN-II) Experiment co-sponsored by the Monterey Bay Aquarium Research Institute (MBARI) and ONR.

APPROACH

Our analyses in the previous year (FY05) showed that the spectral content of near surface fluxes measured with aircraft has different behavior in along and cross sampling with frequency shift of energy to higher frequencies in the later case. Measured heat turbulent transfer coefficients were systematically lower than bulk estimates in both sampling directions while drag coefficients in cross wind sampling agreed with bulk estimates. The boundary layer depth inside Monterey Bay was found to be quite low and this was attributed to low turbulence in the Bay. The issues to be addressed this year are the physical mechanism responsible for the non-isotropic behavior of flux spectra, the cause of the different behavior between momentum and heat flux transfer coefficient and the connection of the spatial distribution of boundary layer depth with synoptic scale flow characteristics. Spectral phase analysis of wind speed components, flux profiles classification and estimation of synoptic scale parameters from NCEP/NCAR reanalysis were the tools used to find the answers to the above questions.

Qing Wang is responsible for the overall project. Dr. John Kalogiros, an external research associate from National Observatory of Athens, Greece, works on the data analysis using a variety of data sources. In situ observations were made by the Twin Otter research aircraft operated by the Center for

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Interdisciplinary Remote Piloted Aircraft Studies (CIRPAS) at the Naval Postgraduate School (NPS) during the AOSN-II experiment.

WORK COMPLETED

1. We performed a spectral analysis of near surface turbulent wind data in order to identify longitudinal rolls in the boundary layer and how we can avoid their effect on turbulence fluxes.

2. We classified the flux profiles in categories depending on the mixing intensity of the boundary layer, we calculated composite flux profiles and hence determined a more accurate estimate of the flux divergence in each category.

3. We calculated synoptic scale parameters in the area of measurements and connected them with the measured near surface flow and the structure (boundary layer height) of the boundary layer.

RESULTS

Longitudinal rolls, phase spectral analysis. Phase spectra analysis of aircraft measurements verified the existence of longitudinal rolls whose effects are significant even close to surface. Figure 1 shows the composite coherence and phase spectra of vertical (w) and cross (v) wind components using cross wind legs (within 20^{o} from cross wind direction). A phase difference between w and v close to $\pm 90^{o}$ is characteristic of longitudinal rolls. The analysis data included legs with <w'v'> flux greater than 0.01 $m^2 s^{-2}$ and boundary layer height $Z_i > 5z$, where z is the average measurement altitude (about 35 m). Rolls circulation results in shift of turbulent energy to higher frequencies in cross wind direction and, thus, cross wind sampling is preferable for shorter averaging legs in order to avoid loosing flux energy contained in low frequencies due to limited averaging length. This effect explains the lower turbulent transfer coefficients presented in last year report under along wind sampling compared to cross wind sampling.

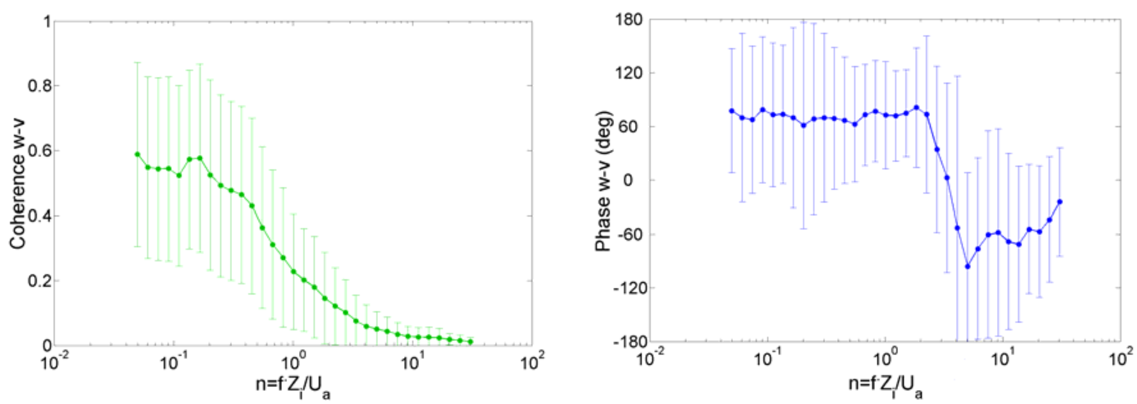

Figure 1: Average with standard deviation of coherence and phase of w, v wind components using cross wind legs.

Flux divergence, flux profiles analysis. Last year's work has shown that turbulent fluxes estimated from AOSN-II near surface aircraft flights are lower than surface fluxes estimates from well known bulk parameterizations even in the cross wind direction probably due to significant flux divergence in the shallow boundary layer depth near the coast. Using potential temperature, water vapor mixing ratio and wind profiles from aircraft soundings, two types of vertical profile were identified. One group of

profiles was characterized by sufficient mixing up to boundary layer depth, which was determined as the base of the steep temperature inversion capping the boundary layer. The other group showed mixing only up to about half the boundary layer depth probably due to morning dissipation of stratocumulus cloud, which covered the area during night and early morning. Figures 2 and 3 show composite the profiles of heat and momentum fluxes for each group with further classification according to stability parameter z/L (L is the Monin-Obukhov length and z is the measurement altitude). Most of the cases in AOSN-II belonged to the not well-mixed group. Thus, in the case of scalar quantities fluxes (such heat flux) the assumption of linear flux profiles with zero value at half the boundary layer depth can be used for reduction of turbulent fluxes measured at near surface flight legs to surface values. In the case of momentum flux divergence close to surface is significantly smaller.

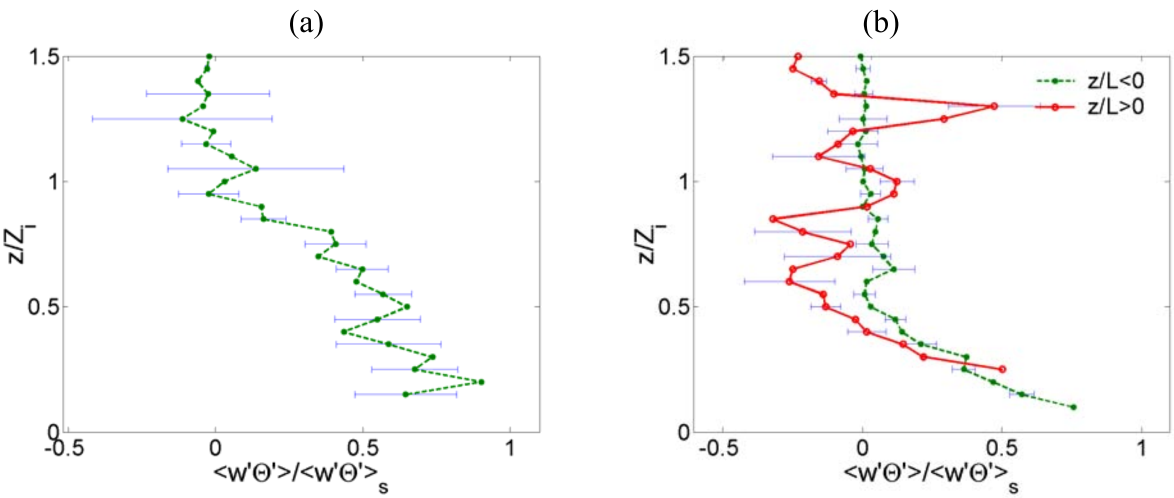

Figure 2: Composite profiles of kinematic heat flux <w'Θ'> normalized with near surface value <w'Θ'>$_s$ and standard deviation of the mean for (a) well mixed and (b) not well mixed cases.

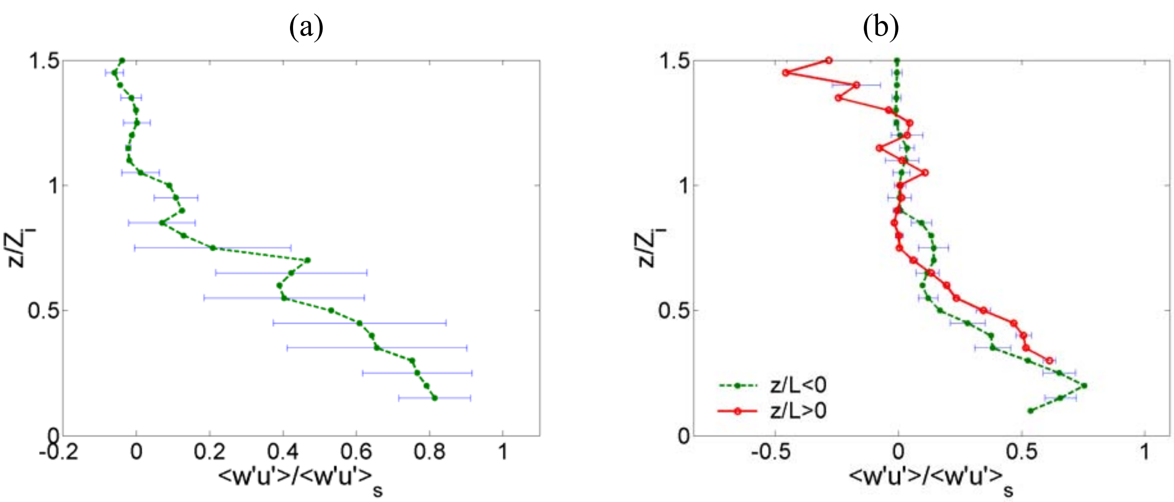

Figure 3: As in Figure 2 but for the momentum flux <w'u'>.

Thus, correction of flux divergence using average normalized flux profiles is significant especially for heat flux and results in agreement of turbulent transfer coefficients with bulk estimates (COARE) under unstable atmospheric stability conditions. Figure 4 shows corrected wind stress C_{dn10} and heat flux C_{hn10} transfer coefficients estimated using the eddy correlation method and reduced to neutral stability conditions at 10 m above surface using similarity profiles. The surface layer values shown

were not corrected for flux divergence. The surface layer was defined as altitudes z below 0.1 Z_i where flux divergence correction is quite small. Under stable conditions measured turbulent transfer coefficients are still lower than bulk estimates, which indicates that higher sampling rate is needed in order to fully resolve eddy fluxes.

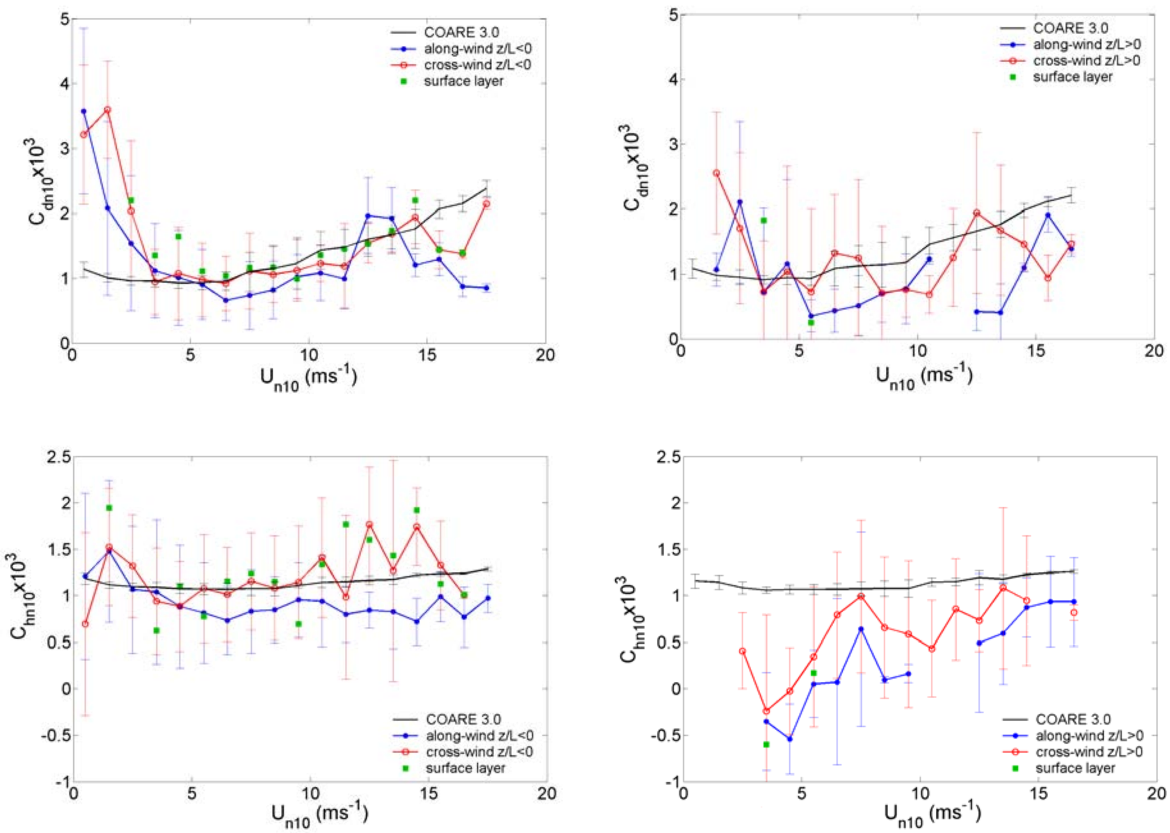

Figure 4: Momentum (C_{dn}) and heat (C_{hn}) flux transfer coefficients after flux divergence correction against wind speed (U_{n10}) at 10 m AMSL.

Boundary layer structure, synoptic scale parameters. Synoptic scale conditions obtained from NCEP/NCAR reanalysis described in last year report were used for correlation analysis with AOSN-II wind field and boundary layer characteristics measured with aircraft. Synoptic parameters calculated at sea surface and 850hPa in the area of aircraft measurements included surface geostrophic wind, thermal gradient and advection, and synoptic scale subsidence velocity. Surface geostrophic wind was in good correlation with measured area average wind apart from a speed reduction and small wind direction turn due to surface friction. Consequently, near surface turbulence and boundary layer growth was also in correlation with geostrophic wind at offshore positions. Figure 5 shows the correlation of surface geostrophic wind with boundary layer height measured at two positions. Near the shore and especially in Monterey Bay the sheltering effect of the coastal mountains results in low boundary layer height. It was also found that these low boundary layer heights can be even lower at the north part of the Bay under high wind from the north which can cause an expansion fan at this area.

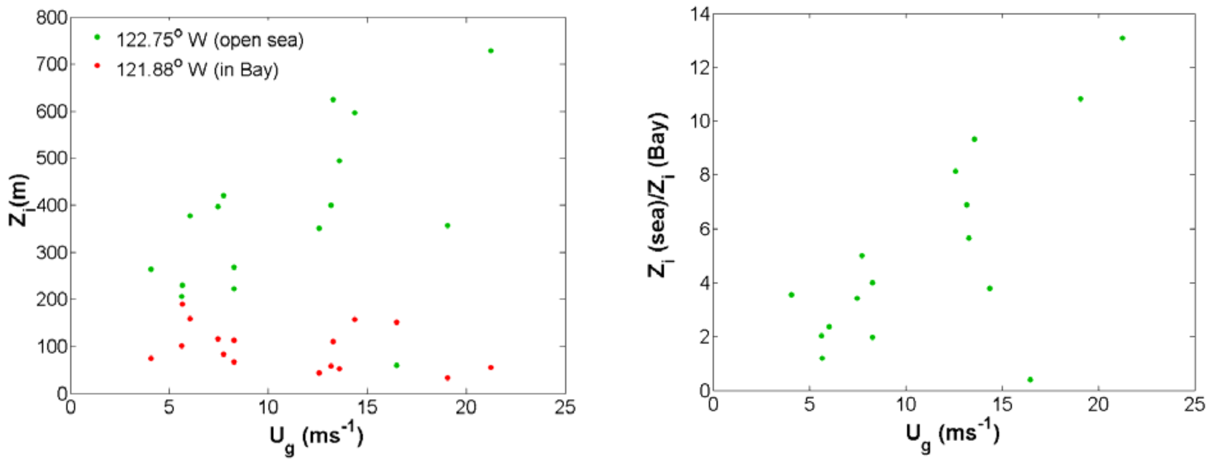

Figure 5: Boundary layer height Z_i and ratio at two positions (offshore open sea and in the Bay) against sea surface geostrophic wind speed (U_g).

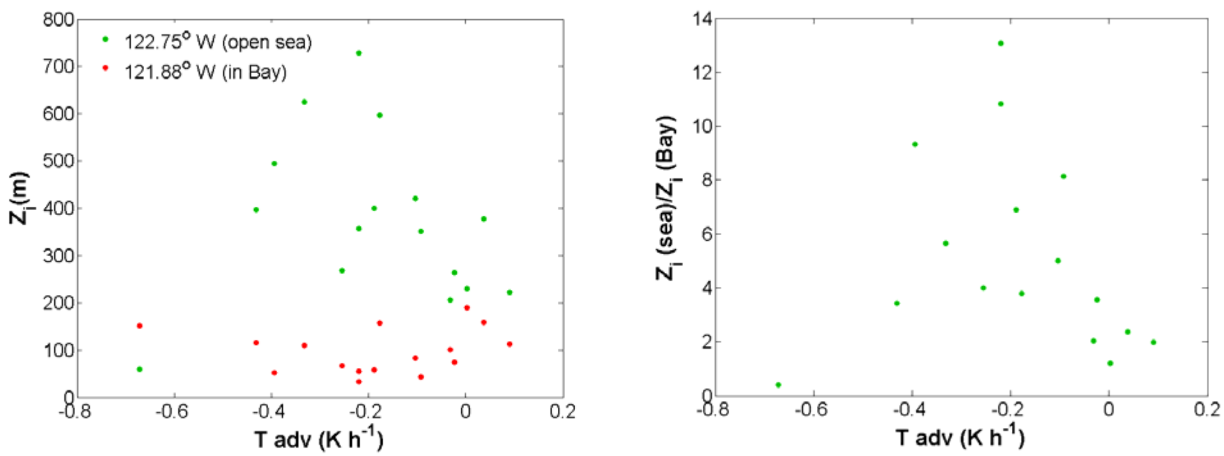

Figure 6. As in Figure 5 but for Z_i against synoptic thermal advection estimated from wind speed and temperature field at 850 hPa (above boundary layer) of NCEP reanalysis.

Cold advection, usually under north wind above the boundary layer, was also observed to increase boundary layer growth at the offshore positions (Figure 6) due to reduction the temperature inversion strength above the boundary layer. The boundary layer in the Bay is low due to weak turbulence. Thus, the effects of cold advection were minimized.

IMPACT/APPLICATIONS

Our observational analysis suggests that longitudinal rolls are present in the marine boundary layer even close to the sea surface along with significant flux divergence due to incomplete mixing in the boundary layer. Their effects on measured near surface turbulence fluxes are significant. Cross wind sampling should be preferred in order to avoid flux loss at large turbulence scales due to limited averaging length. Flux divergence should be accounted for especially in the case of heat (scalar) flux. Taking these effects into account bulk estimates of turbulent transfer coefficients are in agreement with measured coefficients under unstable conditions. Under stable conditions the explanation of the remaining discrepancies requires higher sampling rate (more than 10 Hz of the current dataset) in order to better resolve fluxes. These finding will help in more accurate evaluation of turbulence parameterizations in coastal boundary layers.

TRANSITIONS

The results of this project will potentially help to evaluate and improve the turbulence parameterizations of mesoscale models.

RELATED PROJECTS

Related project is the CBLAST project for surface flux parameterization (NPS award to NPS #N0001406WR20253 and ONR award to NRL #N0001406WX20664).

PUBLICATIONS

Kalogiros, J., Q. Wang, S. Ramp, G. Buzorius and H. Jonsson, (2006): Aircraft observations of marine boundary layer structure in the area of Monterey Bay. *17th Symposium on Boundary Layers and Turbulence*, San Diego, 22-25 May, 2006.

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